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Influences of the Atlantic and Pacific Oceans on Rainy Season Precipitation for the Southernmost Caribbean Small Island State, Trinidad

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Abstract: Seasonal rainfall in the Caribbean Basin is known to be modulated by sea surface temperature anomalies (SSTAs) in the Atlantic and Pacific Oceans, and particularly those in the Equatorial Pacific and Atlantic and the Tropical North Atlantic. However, little is known about how these major oceans influence the seasonal precipitation of individual small island states within the region as climate variability at the island-scale may differ from the Caribbean as a whole. Correlation and composite analyses were determined using monthly rainfall data for the southernmost island of the Caribbean, Trinidad, and an extended area of global SSTAs. In addition to the subregions that are known to modulate Caribbean rainfall, our analyses show that sea surface temperatures (SSTs) located in the subtropical South Pacific, the South Atlantic, and the Gulf of Mexico also have weak ($r^2 < 0.5$) yet significant influences on the islands' early rainy season (ERS) and late rainy season (LRS) precipitation. Composite maps confirm that the South Pacific, South Atlantic, and the Gulf of Mexico show significant SSTAs in December–January–February (DJF) and March–April–May (MAM) prior to the ERS and the LRS. Statistical models for seasonal forecasting of rainfall at the island scale could be improved by using the SSTAs of the Pacific and Atlantic subregions identified in this study.

Keywords: climate variability; precipitation; sea surface temperatures; early rainy season; late rainy season; correlations; composites; Trinidad; Caribbean; rainfall

1. Introduction

Seasonal rainfall is critical to the agriculture sector and economy of Caribbean islands that import a high proportion of their food [1,2]. When domestic food production is disrupted by above-normal or below-normal rainfall [3,4], in drought or floods, food imports are increased to compensate for the loss of crops, thereby introducing a strain in islands with limited financial resources and imposing competition between famers and imported products [5]. Farmers depend on seasonal forecasts to take preventative measures for a successful harvest and security of livelihoods. The Caribbean Institute for Meteorology and Hydrology (CIMH) provides seasonal forecasts of rainfall for the Caribbean islands by making use of sea surface temperature (SST) and in-situ observations of rainfall in each island as predictors [6]. Statistical predictions are corroborated with probabilistic forecasts from atmosphere–ocean general circulation models (AOGCMs) through the Climate Predictability Tool [7], and drought forecasts are provided three months in advance for several Caribbean subregions [8].

Seasonal rainfall variability across the Caribbean is influenced by the tropical Atlantic and Pacific [9–15]. Sea surface temperatures (SSTs) in the Atlantic and Pacific Oceans influence Caribbean precipitation in the rainy season, which can be divided into an early rainy season (ERS) (May–June–July) and a late rainy season (LRS) (August–September–October) [9,10,12,15,16]. Inter-annual variability in Caribbean ERS rainfall is primarily related to the tropical North Atlantic's sea surface temperature anomalies (SSTAs), whereas inter-annual variation in LRS rainfall is associated with SSTAs in both the Pacific and the Atlantic [12,14–17]. A wet ERS is associated with a warm Tropical North Atlantic (TNA) [14,17]. The oppositely signed warm Pacific and cool Atlantic are associated with reduced rainfall in the LRS [12,16,18]. The presence of a meridional dipole across the Intertropical Convergence Zone (ITCZ) in the Tropical Atlantic and oppositely signed SSTAs in the eastern Tropical Pacific and the Tropical North Atlantic are precursors to the strongest rainfall response in the Caribbean [18], which is primarily a LRS response [12,14]. The East–West SST gradient of the LRS is not associated with the ERS. In addition, the El Niño-Southern Oscillation (ENSO) phenomenon influences inter-annual variability in the Caribbean's ERS [13].

Although the Tropical Pacific and Atlantic Oceans influence Caribbean seasonal rainfall, the strength of their impacts could vary regionally and seasonally. Few studies have focused specifically on the rainfall variability in the southern Caribbean [19–22] and the degree to which SSTs influence rainfall. An understanding of the influence of the oceans on island-scale seasonal precipitation is much needed to implement appropriate preventative measures for preserving crop harvests. Ingram and colleagues [23], through a survey of farmers in Burkina Faso, found that farmers need forecasts on local scales at the farm sites relevant to them. This observation is applicable to the Caribbean as individual small islands can be considered to be local in comparison to the Caribbean Basin.

In addition, islands spread across an area may experience the effects of rainfall modulators to different degrees. For instance, the southernmost island of the Caribbean, Trinidad, by virtue of its latitudinal location, lies just outside the hurricane belt of the Caribbean and has not been drastically affected by hurricanes since 1963 [24,25]. Furthermore, the island's rainfall is directly influenced by the Intertropical Convergence Zone (ITCZ), unlike the higher latitude Caribbean islands. Other Caribbean islands to the north of Venezuela, the Dutch Caribbean (ABC islands), have rainfall patterns that are different to those expressed for the Caribbean Basin in terms of start and end dates of their dry and wet seasons [26]. Thus, some aspects of the dynamics governing island rainfall may be masked by considering the influence of factors on the area-averaged Caribbean precipitation. As such, forecasts for rainfall tailored to each island may be beneficial to farmers.

One critical aspect of improving statistical forecast models is to understand the influence of the predictors on the forecast variable. For the Caribbean, some of these relationships were determined using SST indices such as the NINO3 SSTA index (5° N–5° S, 150° W–90° W), NINO3.4 SSTA index (5° N–5° S, 170°–120° W), the Tropical South Atlantic (22° S–02° N, 35° W–10° E) and the North Atlantic (6° N–22° N, 80° W–15° W) indices [9,16]. These indices were also looked at in addition to the Equatorial Atlantic (5° S–5° N, 15° W–0° W) [12]. However, island-scale precipitation responses to SSTAs of the typical subregions of the Pacific and Atlantic may differ from those of the Caribbean as a whole. It is often assumed that the oceanic regions defined above affect all islands of the Caribbean. In addition, these regions are limited to 22° S to 22° N. Other subregions of the Pacific and Atlantic that have not been previously considered may also have an influence on island-scale rainfall variability. As such, an SST domain of a wider latitudinal extent should be explored.

Therefore, in this work the influences of SSTs in the Atlantic and the Pacific Oceans on the seasonal rainfall of an individual island state in the Caribbean region, Trinidad, are explored through correlation and composite analyses with the SST domain extending from 50° S to 50° N. Correlation analyses quantify the strength of the linear relationship between SSTs and rainfall and assist in identifying the subregions of the Pacific and Atlantic Oceans that influence an individual island's rainfall. Composites of SSTA patterns provide a snapshot of the state of the sea surface temperatures when seasonal rainfall in the island state is above and below one standard deviation from the mean early and late rainy season rainfall. The SST domain that is considered in this study is wider than that considered in previous studies [9,12,14,16,18] and allows for the identification of the subregions of the oceans that may have an influence on the island's precipitation.

This paper is structured as follows. Section 2 contains a description of the study area, the data sets, and the methodology used in the analysis. In Section 3, we highlight the main results of the correlation and composite analyses and identify the subregions of the Atlantic and Pacific that influence precipitation variability from global SSTA–island-precipitation correlation maps. Section 3 also discusses the influence of large-scale inter-annual variability of SSTAs on the individual small island's precipitation in comparison to the entire Caribbean region response. Finally, in Section 4, the conclusion, we summarize the implications drawn from the present study in developing an appropriate statistical seasonal forecast model for the Caribbean island of Trinidad and how this study could further the research on the influence of oceanic factors on island rainfall.

2. Materials and Methods

2.1. Study Area

The focus of this study is on Trinidad, the southernmost island of the twenty-eight (28) islands in the archipelago bounded by the Caribbean Sea. It is the larger island of the twin-island Republic of Trinidad and Tobago and is geographically located between 10°2′ and 11°12′ N, and 60°30′ and 61° 56′ W. It is approximately 5128 km^2 combined (Figure 1) [27]. The islands experience two seasonal climates, tropical maritime and modified moist equatorial, which result in a dry period from January to May and a rainy season from June to December [28]. The transitional periods, late May and December [28], tend to exhibit both dry and wet conditions.

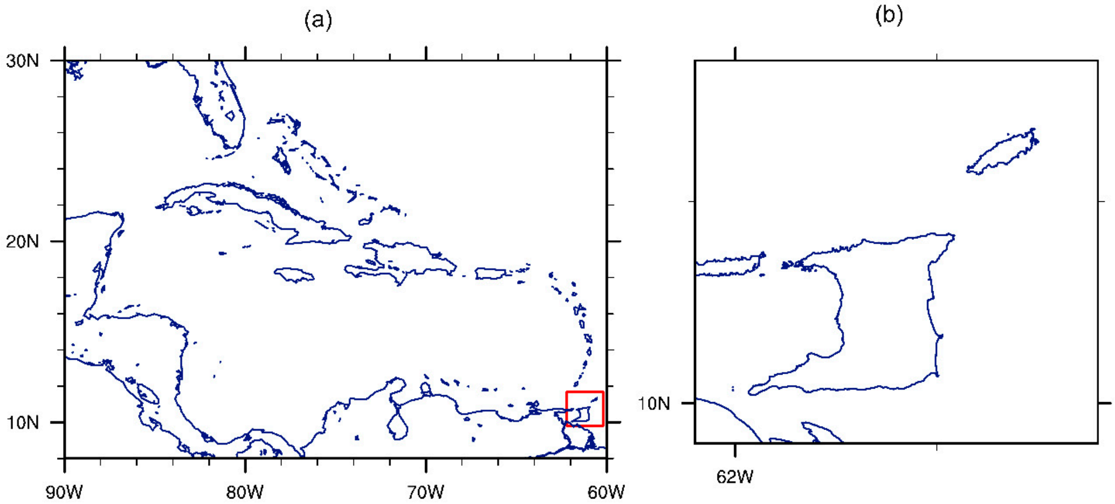


Figure 1. Maps of (**a**) the Caribbean Basin and (**b**) the twin island state of Trinidad and Tobago, which is highlighted in (**a**) with a red box.

2.2. Data Sets

2.2.1. Precipitation (PPT) Data Sets and Precipitation Climatology

Monthly precipitation data were obtained from the Trinidad and Tobago Meteorological Service (TTMS)'s Piarco station located at 10.62° N, 61.35° E [29]. Precipitation data were collected and recorded via rain gauges by the TTMS according to the standards set by the World Meteorological Organization (WMO). These can be found in the Commission for Instruments and Methods of Observation (CIMO) Guide [30]. There are approximately thirteen (13) other stations with varied time periods for Trinidad. Among these stations, the longest common precipitation time period is from 1980 to 2014. This gives thirty-five (35) years of data [31]. The precipitation dataset from the Piarco station for the period of

1946–2006 is the only suitable available data set for assessing long-term inter-annual variations as the sixty-one (61)-year time series does not contain abrupt change-points [21]. The rainfall climatology at the Piarco station (Figure 2) is considered here to be representative of the rainfall climatology of Trinidad as the meteorological station is located in flat plains with minimal orographic influence.

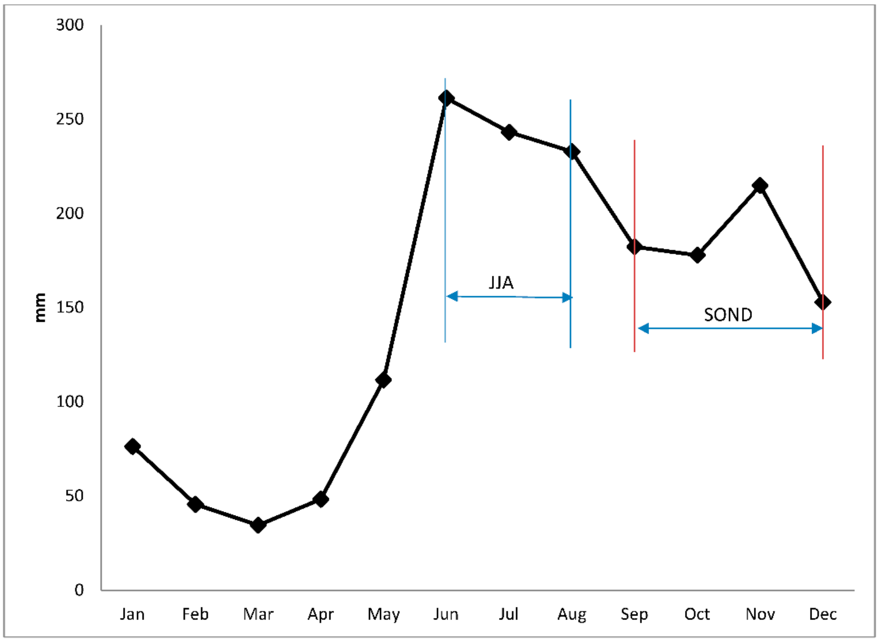


Figure 2. Monthly precipitation climatology (mm, 1946–2006) for Piarco, Trinidad, showing the early (June–July–August, JJA) and late (September–October–November–December, SOND) rainfall seasons. Precipitation data were obtained from the Trinidad and Tobago Meteorological Service (TTMS).

Precipitation in Trinidad shows similarities but also has distinct features when compared to the average rainfall of the entire Caribbean region. They both have reduced rainfall during January–February–March (JFM) and a mid-summer dry (MSD) period during their rainy seasons. The MSD period is identified as the time between the first and second rainy season precipitation maxima [32]. Rainfall climatology for the southernmost island of the Caribbean differs (Figure 2) from that of the Caribbean (Figure 3) in the timing of the primary and secondary maxima. The intra-annual variation of rainfall in Trinidad has two maxima with the first peak occurring in June or July and the second in November [33]. The precipitation climatology for Trinidad for the period of 1946–2006 (Figure 2) shows the early (June–July–August) (JJA) and late (September–October–November–December) (SOND) rainy seasons. In contrast, the intra-annual variation of the Caribbean rainfall is characterized by two rainfall maxima with the primary peak occurring in October and the secondary rainfall maximum in June (Figure 3). The Caribbean's average monthly precipitation totals in Figure 3 were obtained from the Global Precipitation Climatology Centre (GPCC) for the period of 1981–2016 [34]. The gridded gauge-based data comprise of quality-controlled data sets of ten (10) years or longer from sixty-seven thousand and two hundred (67,200) stations located worldwide. The analysis product contains monthly totals on a regular grid of a 2.5° × 2.5° latitude by longitude spatial resolution. The time series was calculated from monthly totals averaged over the area of 10°–20° N, 65°–83° W. In addition, we note that the monthly climatology for Caribbean precipitation obtained from an area average of station data from twenty-two (22) islands by Chen and Taylor [13] characterize a relatively dry winter [10,12,31] from December to March and an early (April–July) and a late (August–November) rainy season. The observed monthly climatologies for Trinidad and the Caribbean are supported by station pentad rainfall climatologies by Martinez et al. [35], who found that "the bimodal rainfall pattern in Trinidad and Guianas is distinct from the climatological bimodal pattern seen in most of the Caribbean."

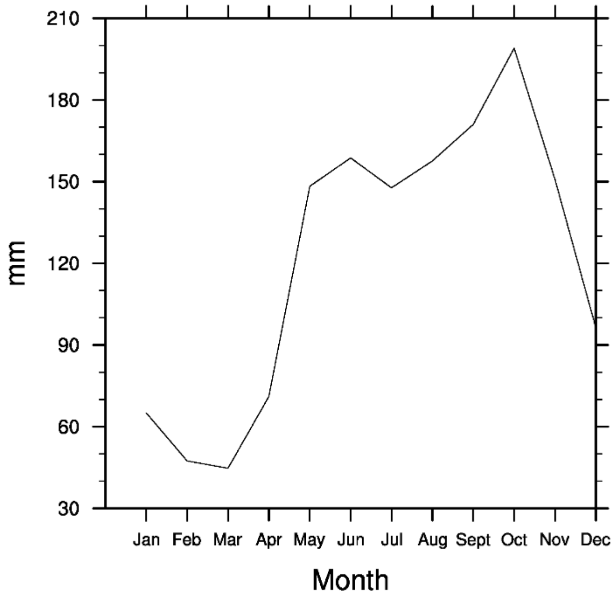


Figure 3. Caribbean's average monthly precipitation totals obtained from the Global Precipitation Climatology Centre (GPCC) for the period of 1981–2016 [34]. This GPCC precipitation was provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, through their website at https://www.esrl.noaa.gov/psd/.

2.2.2. Sea Surface Temperatures (SSTs)

The SST data set (1946–2006) produced by the Hadley Centre for Climate Change, United Kingdom Meteorological Office, was used in this study. This SST data set has monthly global fields of SST on a 1° × 1° latitude–longitude global grid (89.5° S–89.5° N and 1° E–359.0° E) and is a combination of in-situ observations along with bias-adjusted satellite observations from the Advanced Very High Resolution Radiometer (AVHRR) [36]. This dataset was obtained from the National Center for Atmospheric Research (https://climatedataguide.ucar.edu/climate-data/sst-data-hadisst-v11). SST data for the period of 1946 to 2006 were used as the period coincides with that of the homogeneous precipitation data.

2.3. *Methods*

For this study, the methodology involved the computation of anomalies, correlation analyses between the anomalies for the SSTs and precipitation (PPT), and composite analyses. These allowed the effects of the global climate systems to be highlighted and links to be made between Trinidad's rainfall and SSTs. In the present study, the seasonal sea surface temperature anomalies (SSTAs) were denoted as December–January–February (DJF), March–April–May (MAM), June–July–August (JJA), and September–October–November (SON). The rainfall seasonal definitions for Trinidad were referred to in the following sections as early rainfall season (ERS: JJA) and late rainfall season (LRS: SOND).

2.3.1. Anomalies

Monthly SSTAs and precipitation anomalies (PPTAs) were normalized by subtracting the monthly mean from the monthly averages of SST or precipitation and dividing by the monthly standard deviation. These anomalies were used in the production of the correlation and composite maps.

2.3.2. Correlation Analysis

The Pearson product-moment of the correlation coefficient (r) is the result of correlation analysis and was used to measure the degree of linear association between two data fields. The correlation coefficient takes values in the interval [−1, 1], which indicate the strength of the correlation [37–39]. Global, monthly lag–lead and seasonal correlation maps were produced for SSTAs in the region between 50° N to 50° S and 180° W to 10° E and Trinidad's monthly precipitation (1946–2006) to capture both the Atlantic and Pacific Oceans' influences. Lag–lead correlations were performed for SSTA lag zero (0) months, SSTA lead three (3) months, and SSTA lead six (6) months. All correlation maps exhibit only correlations that exceed the 95% confidence level according to the student's *t*-test.

2.3.3. Construction of Composite Maps

Composite maps were constructed using the years with precipitation values that were greater than or less than one standard deviation of Trinidad's precipitation anomaly (PPTA) for the ERS (JJA) for the period of 1946 to 2006. Due to the small range of values from the precipitation data set, one standard deviation was applied [40] to indicate the most prominent rainfall anomalies. The years with a precipitation anomaly (PPTA) exceeding one standard deviation (Table 1) were used to produce the composite maps of the "wet" early rainy (JJA) season. Composite maps show features that are statistically significant through a *t*-test applied at the 95% confidence level [38]. Similarly, the years with PPTA below one standard deviation were used in computing the "dry" JJA composite map [40,41]. The resulting thirteen (13) "wet" and ten (10) "dry" years were averaged to produce maps for DJF, MAM, and JJA seasons for SSTA. This procedure was repeated for the LRS for Trinidad. Eleven (11) "wet" and nine (9) "dry" years were averaged to produce the LRS SSTA maps. This averaging for the DJF, MAM, JJA, and SON seasons allowed for the impactful surface oceanic phenomena of the Atlantic and Pacific Oceans to be highlighted [42] during above-normal and below-normal ERS and LRS for the southernmost Caribbean island of Trinidad.

Table 1. Years used in the compilation of early and late rainy season composite maps for the period of 1946 to 2006.

Trinidad's Early Rainy Season (JJA)		**Trinidad's Late Rainy Season (SOND)**	
Above Normal (Wet Years)	**Below Normal (Dry Years)**	**Above Normal (Wet Years)**	**Below Normal (Dry Years)**
1948	1957	1948	1946
1949	1959	1950	1947
1950	1971	1951	1959
1951	1972	1956	1969
1955	1974	1958	1978
1958	1982	1972	1984
1964	1986	1976	1987
1969	1987	2000	1988
1970	1989	2002	2003
1979	1991	2004	
1984		2006	
1998			
2006			

3. Results and Discussion

3.1. Correlations

3.1.1. Global Monthly Correlations

Trinidad's monthly rainfall is negatively correlated with the tropical Pacific SSTAs in the region of 30° N to 10° S and 80° W to 180° W (NINO3 and NINO3.4 Index regions) within the Tropical Pacific (Figure 4). The island's rainfall anomalies are also positively correlated with SSTAs just south of this region in the Pacific, thereby giving rise to a dipole of negative and positive correlations in the Pacific. The Pacific's dipole of correlations dominates from 10° N to 30° S. The Tropical North Atlantic (TNA) also plays a dual role in monthly precipitation (Figure 4), as shown by the positive and negative correlations located at 30° N–5° S and 60°–20° W in the TNA. In the South Atlantic, there is a region of weak negative correlations with significant magnitudes between −0.05 to −0.10.

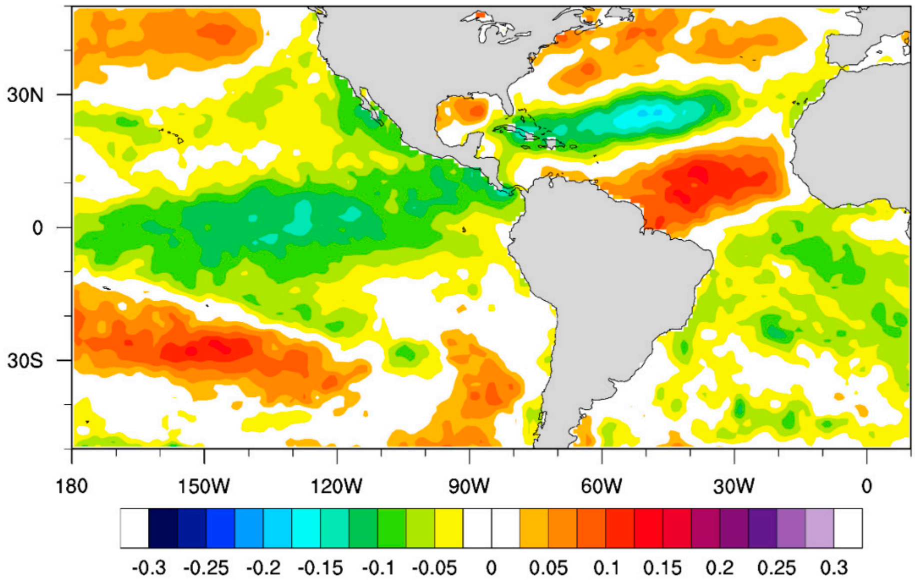


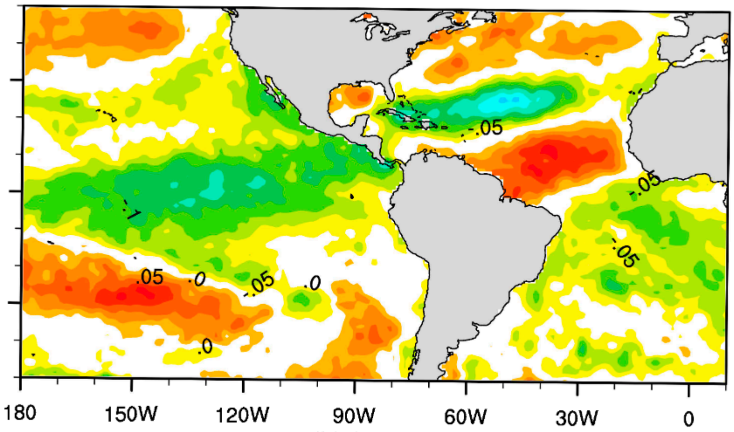
Figure 4. Correlation map for Trinidad's monthly rainfall anomalies and concurrent global monthly sea surface temperature anomalies (SSTAs).

At concurrent time, the Gulf of Mexico is positively correlated with rainfall. Just adjacent to this region of positive correlations is a region of negative correlations with SSTAs in the Caribbean Sea. Therefore, the positive correlations in the Gulf of Mexico appear to be a localized effect. A region of positive correlations develops below the region of negative correlations and forms part of the Atlantic dipole between the northeastern coast of South America and the northwestern coast of Africa.

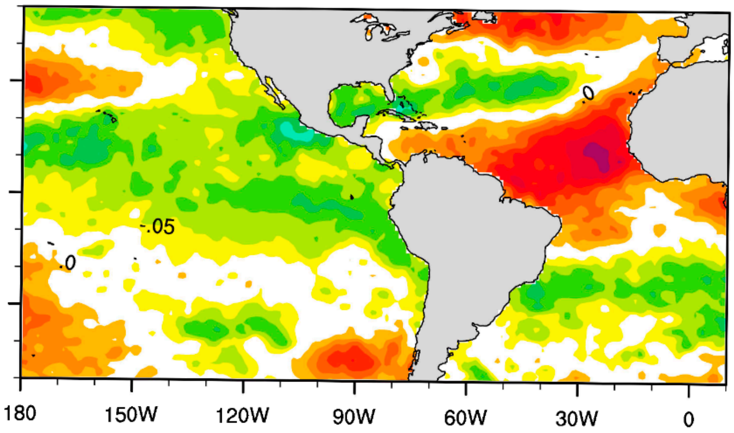
3.1.2. Lag–Lead Monthly Correlations

When SSTAs lead PPTAs by 3 months (Figure 5b), large parts of the Pacific Ocean and the Gulf of Mexico are negatively correlated with precipitation in Trinidad. The dipole of correlations associated with the Pacific at lag 0 (Figure 5a) is no longer present, leaving only SSTAs that are negatively correlated with Trinidad's rainfall. The Tropical Atlantic Ocean and the Caribbean Sea, on the other hand, are positively correlated with Trinidad's PPTA. The dipole of correlation formed in the Atlantic at lag 0 is weaker than the Atlantic dipole when SSTAs lead PPTAs by 3 months, as seen in Figure 5b. However, it should also be noted that when SSTAs lead PPTAs by three months (Figure 5b), the intensity of the correlation in the Pacific is smaller in magnitude (Figure 5b,c) and the dipolar influence of the Pacific is no longer present. At lead 6 months (Figure 5c), the Caribbean Sea and the Tropical Atlantic are still positively correlated with Trinidad's PPTA, while the Pacific's signal is negligible.

(a) lag + 0



(b) lag + 3



(c) lag + 6

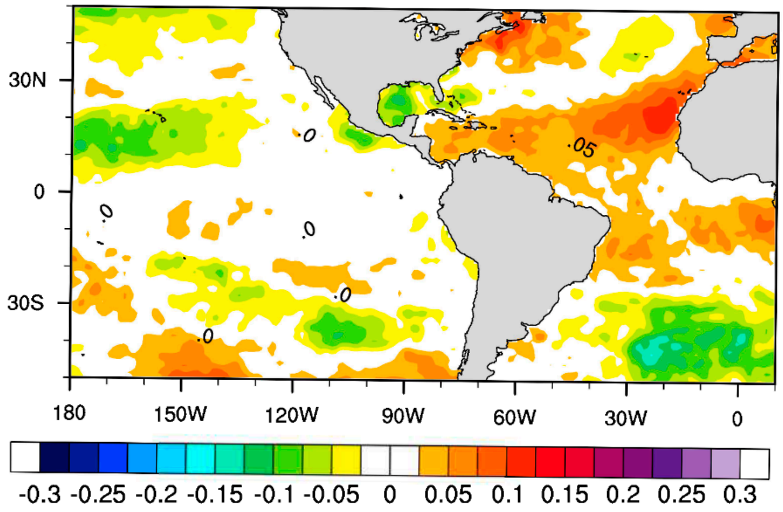


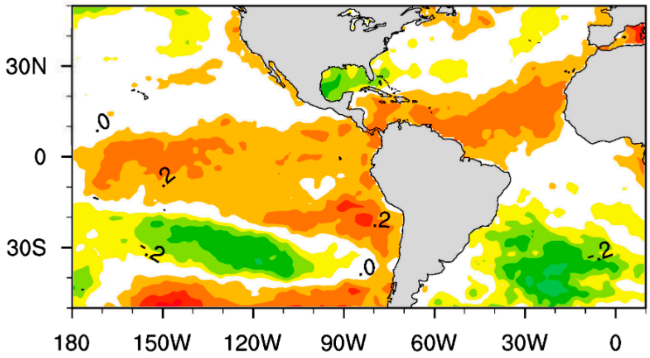
Figure 5. Lag–lead correlations between global monthly SSTAs and Trinidad's monthly precipitation anomalies. Statistically significant correlation maps showing (**a**) lag 0 months, (**b**) SSTA leads by 3 months, and (**c**) SSTA leads by 6 months.

The correlations between monthly PPTAs and SSTAs mask the effect of SSTAs on the early and late seasons, the main seasons affecting agriculture practices in Trinidad. The correlations between monthly PPTAs and SSTAs do not indicate which season's SSTAs may be related to ERS or LRS precipitation; therefore, there is a need to perform seasonal correlations.

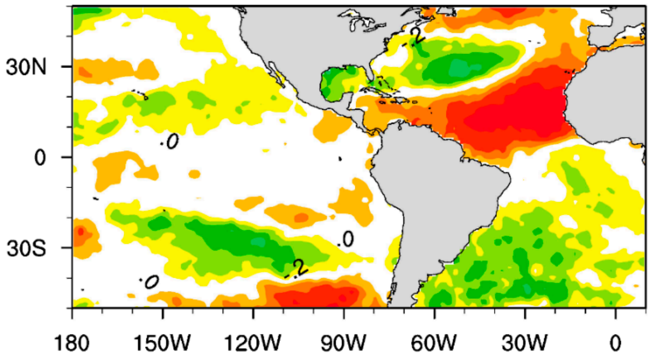
3.1.3. Early Rainy Season Correlations

The seasonal correlations of Figure 6a show that the DJF SSTAs in the NINO3 and NINO3.4 regions and south of the NINO3 and NINO3.4 regions in the Equatorial Pacific, the Caribbean Sea, the Gulf of Mexico, the TNA, and the South Atlantic significantly influence Trinidad's ERS (JJA). The NINO3 and NINO3.4 regions form one arm of the Pacific dipole in DJF and provide an enhancing effect on ERS rainfall (Figure 6a). However, as the DJF SSTAs transition into the MAM SSTAs (Figure 6b), the influence of the SSTAs in the NINO3 and NINO3.4 regions weakens and the correlations of the Pacific dipole decay. At the same time, correlations appear to intensify in the TNA and the Caribbean Sea and become dominant over the Pacific. Maximum correlation coefficients in the TNA increase from +0.3 to +0.5.

(a) DJF SSTA & JJA PPTA



(b) MAM SSTA & JJA PPTA



(c) JJA SSTA & JJA PPTA

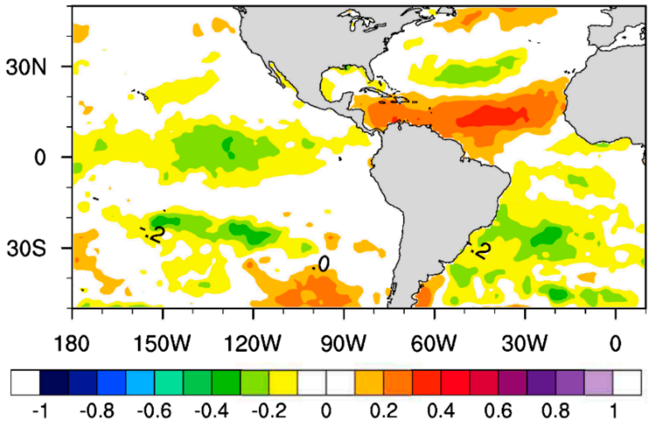


Figure 6. Correlations between Trinidad's early rainy season (ERS) (JJA) precipitation anomaly PPTA and seasonal SSTAs. Correlation maps show (**a**) December–January–February (DJF) SSTAs and JJA PPTA, (**b**) March–April–May (MAM) SSTAs and JJA PPTA, and (**c**) JJA SSTAs and JJA PPTA.

As the Pacific influence decays from DJF SSTAs to MAM SSTAs, a dipole pattern indicating the dual influence of the TNA appears. In addition to this, we note the weak negative modulating role of SSTAs in the subtropical South Atlantic Ocean and the Gulf of Mexico preceding the ERS.

Correlation analyses of the concurrent JJA SSTAs with early season (JJA) PPTA (Figure 6c) show four features. Firstly, a positive zonal correlation from the Caribbean Sea to the Tropical Atlantic along the 10° N line is apparent. The positive zonal correlation along the 10° N line in the Atlantic coincides with the Intertropical Convergence Zone (ITCZ) band, which lies between 10° S and 10° N [43]. Variations in the meridional direction of this ITCZ centerline have been known to cause variation in deep convection processes [44] and thus act as an enhancer for Trinidad's rainfall. However, the influence of this zonal SSTA is weaker in comparison to the previous MAM season's SSTA (Figure 6b). Secondly, in the Pacific there is a negative zonal correlation along the 10° N line, and thirdly, the Gulf of Mexico correlation in the ERS (JJA) disappears; however, the previous DJF and MAM SSTAs have a negative influence. The fourth feature is that the ERS rainfall and South Atlantic SSTs between 30° S–50° S, 40° W–0° in DJF are negatively correlated with correlations between −0.3 and −0.4 (Figure 6). The negative influence decreases in magnitude as the season progresses into MAM and then JJA (which is concurrent with the ERS). Maximum correlations at concurrent time were −0.1. Negative correlations initially in the Gulf of Mexico during DJF and MAM decrease in magnitude until they are non-existent by the ERS.

The Pacific and Atlantic Oceans play significant roles in the island state's precipitation at different times of the year. DJF SSTAs in the Pacific have a dipolar effect on ERS rainfall, while the Atlantic has only an enhancing effect on precipitation (Figure 6a). However, the Pacific dipolar influence decays in MAM (Figure 6a,b), while the TNA dipole becomes the dominant influence on Trinidad's ERS rainfall. This amplification of correlations in the TNA in MAM, between 0° N and 20° N, has also been observed for area-averaged Caribbean precipitation [17,44,45].

3.1.4. Similarities and Differences in Correlations between Trinidad's ERS and Ocean SSTAs in Comparison with Those for the Caribbean ERS

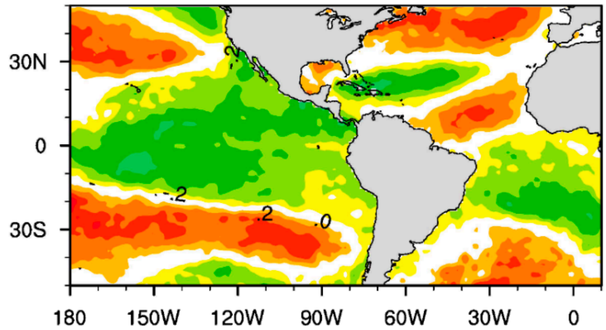
The values of the seasonal correlations for Trinidad's ERS are similar yet different when compared to correlation values obtained for the Caribbean region's ERS. The MAM season SSTAs in the TNA and Caribbean Sea have positive significant correlations with ERS rainfall for both the Caribbean region's rainfall (MJJ) [16] and Trinidad's (JJA) rainfall, respectively. From Figure 6a–c we see these correlations decrease from MAM to JJA. JJA Equatorial Pacific SSTs are significantly associated with depressed ERS rains (Figure 6c), while JJA SSTA correlation with the Caribbean region's ERS showed the three Niño regions as being not significant with positive magnitudes in Niño 3.4 and 4 regions [16]. It should also be noted that the Caribbean SSTAs are positive and significant in all the seasons leading up to the ERS for both the Caribbean region [16] and Trinidad.

3.1.5. Late Season Correlations

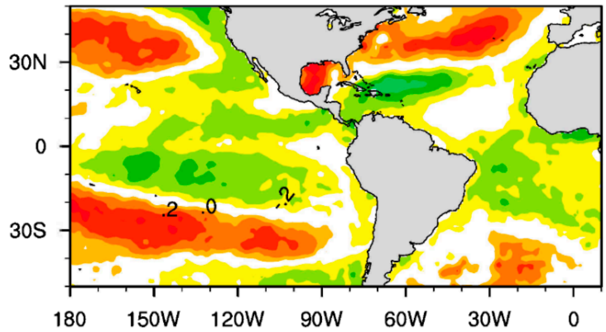
Most of the eastern Pacific (50° S–50° N, 180° W–80° W) and the Atlantic tend to influence LRS rainfall anomalies (Figure 7a). DJF and MAM SSTAs across the North–South extent of both the Pacific and Atlantic affect Trinidad's LRS rains (Figure 7a,b). The Equatorial Pacific has correlations between −0.1 and −0.4, while the subtropical Pacific along 30° S and 30° N has positive correlations between +0.1 and +0.4. The Pacific's SSTA responses appear to be symmetrical about the Equator, leading to a dipole of correlations.

In the Tropical Atlantic, the dipolar influence is present (Figure 7a) just as in the ERS (Figure 6b). There is an area of positive correlations north of the region denoted as the Tropical North Atlantic, 30° N–50° N, which indicates that the DJF subtropical Atlantic tends to enhance LRS rainfall. Similarly, the dipole of correlations in the Pacific with ERS rainfall is also seen for the LRS but is accompanied by significant correlations with the North Pacific. The dipolar effects of the Pacific and the Atlantic on the LRS weaken from DJF into JJA (Figure 7a,c). Weak positive values ranging from +0.1 to +0.3 are observed in the NINO3 and NINO3.4 regions, and weak negative values up to −0.3 are observed below the NINO3 and NINO3.4 regions. SSTAs in the NINO3 and NINO3.4 regions during SON have a small positive effect on the concurrent LRS rainfall. The Tropical Atlantic in MAM only has a negative effect, with correlation values ranging between −0.1 to −0.4.

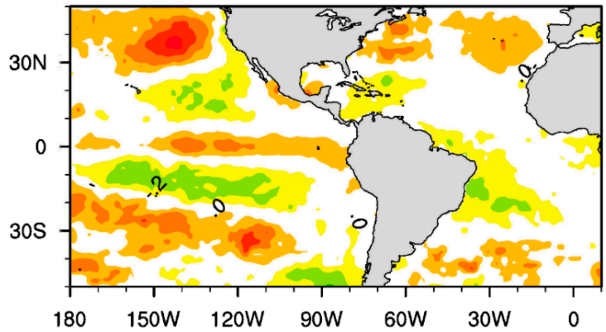
(a) DJF SSTA & SOND PPTA



(b) MAM SSTA & SOND PPTA



(c) JJA SSTA & SOND PPTA



(d) SON SSTA & SOND PPTA

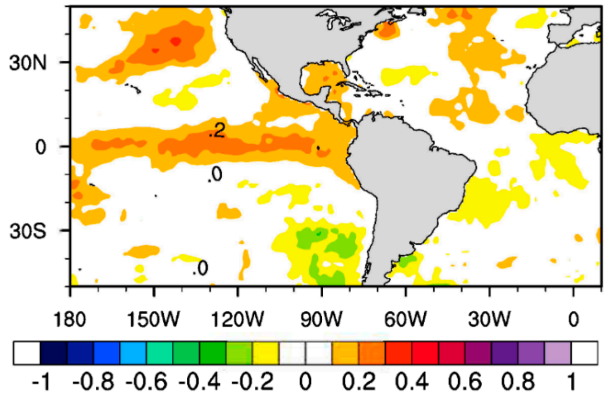


Figure 7. Correlation between Trinidad's late rainfall season (SOND) PPTA and seasonal SSTAs. Correlation maps for (**a**) DJF SSTAs and SOND PPTA, (**b**) MAM SSTAs and SOND PPTA, (**c**) JJA SSTAs and SOND PPTA and (**d**) SON SSTAs and SOND PPTA.

3.1.6. Similarities and Differences in Correlations between Trinidad's LRS and Ocean SSTAs in Comparison with Those for the Caribbean LRS

The Equatorial Pacific has a suppressing effect on Trinidad's LRS rainfall, while the subtropical Pacific along 30° S and 30° N is associated with an enhancing effect on the LRS rainfall. The Pacific's SSTA responses appear to be symmetrical about the Equator (Figure 7a), leading to a dipole of correlations. However, the intensities of the correlation differ for the LRS in comparison to the ERS. This behavior has not been noted for Caribbean rainfall. Past studies [14] have focused on the state of the oceans when seasonal rainfall is above or below normal rather than whether a change in SSTA is correlated with a change in rainfall amounts.

The influences of SSTs of the Caribbean Sea, TNA, and Pacific Ocean on the LRS of the southernmost Caribbean island are opposite to their area-averaged influences on Caribbean rainfall. This may be an artifact of area-averaging to determine the regional rainfall, which may mask the opposite effect of the SSTs on the southernmost island's rainfall. For the DJF season leading to the Caribbean region's LRS (August–September–October–November, ASON), the Caribbean Sea, TNA, and Pacific Ocean SSTAs have positive influences on the LRS, with only the SSTAs in the Caribbean Sea being statistically significant [16]. On the other hand, the SSTAs in the Caribbean Sea and the Equatorial Pacific regions with parts of the TNA have significant negative correlation values with Trinidad's LRS (Figure 7a,d). In addition, correlation magnitudes for these areas decrease from DJF to MAM for Trinidad's LRS (Figure 7a,b). In the MAM season, only the TNA SSTAs are significant (positive) for the Caribbean region's LRS [16]. Here we note that for Trinidad's LRS, the correlations are negative for all of the areas highlighted (Caribbean Sea, Equatorial Pacific region, and part of the TNA) (Figure 7b). During the JJA period, only the Caribbean Sea has a significant positive influence on Caribbean rainfall in the LRS [16], whereas the effect is small but significantly negative (−0.1 to −0.4) on Trinidad's LRS rainfall. During SON, SSTAs in the Niño regions act as the sole influence on Trinidad's LRS (Figure 7d), while Caribbean SSTAs (positive) and Niño 3 and 3.4 regions (negative) have a significant influence on the Caribbean's LRS [16]. While both the ENSO region and TNA affect Caribbean LRS rainfall [12], correlation analyses in this study show that only the Pacific modulates the LRS in Trinidad, although this influence is a weak one.

3.1.7. Dual Role of the Oceans in Seasonal Rainfall through Distinct Correlation Dipole Features

Distinct dipole features in the Pacific and Atlantic were observed on the correlation map of concurrent monthly precipitation–SSTA (Figure 4) as well as seasonal maps six to three months prior to the ERS and the LRS of Trinidad (Figures 6 and 7). This indicates that SSTAs in different regions of the Pacific and Atlantic are simultaneously associated with a suppression and an enhancement of rainfall in the small island of Trinidad. The TNA's observed dual role (positive and negative correlations) is similar to what is observed for the Caribbean. Wang et al. [46] previously identified the positive and negative correlations located at 30° N–5° S, 60°–20° W in the TNA pattern as being coherent SSTAs of dual sign in the Atlantic Ocean in relation to seasonal precipitation within the Caribbean. In addition, when SSTAs lead PPTAs by 3 months, the negative region of correlations within the Caribbean (Figure 5b) corresponds to the Caribbean Sea SST (CSST) Index identified by Chen and Taylor [13] and the region of positive correlations in the Tropical Atlantic Ocean corresponds to the TNA SST Index [16]. In this study, the region of negative correlations in the TNA extends beyond the region defining the CSST to the East into the Atlantic.

Previous studies considered the influence of a smaller region of the Pacific on Caribbean rainfall; therefore, the dual role of the Pacific on Trinidad's rainfall observed here may not have been noted. Most previous studies have focused on the NINO 3, 3.4, and 4 regions, where the SSTs dominate Caribbean rainfall. By extending the domain southward and to the West, we note that the South Pacific has an influence on the rainfall climate of the southernmost island of the Caribbean. In a previous study, Enfield [9] analyzed the influence of the Pacific SSTA index (6° N to 6° S, 90° W to 150° W) on terrestrial rainfall between 50° N to 50° S. Enfield [9] found that the Pacific SSTA index is negatively correlated with precipitation for the Caribbean region. Subsequent studies on the influence of the Pacific and Atlantic Oceans on Caribbean rainfall also considered a domain extending from 45° N to 35° S [10,12,14]. This study indicates that there may be benefit in considering an extended region of the oceans on Caribbean rainfall. In addition, since we computed grid-point SSTA and precipitation correlations rather than correlating PPTAs with area-averaged SSTAs of specific regions, our analyses indicate that several Pacific regions should be defined for computing SSTA area-averaged indices, including the well-known NINO regions and the area between 30° S–20° S and 120° W–180° W.

3.1.8. Role of the Oceans Leading up to Seasonal Rainfall

The two major oceans play a role in the seasons leading up to both ERS and LRS rainfall, but to different extents. DJF SSTAs in the Tropical, South, and North Pacific and Atlantic Oceans affect the LRS. DJF SSTAs in the Tropical and South Pacific and Atlantic Oceans also influence the ERS rainfall. The roles of the oceans weaken in transitioning to the ERS and LRS, leading to weak influences from both oceans contributing to the ERS and just the Pacific for the LRS. The influence of Pacific DJF SSTAs on area-averaged Caribbean rainfall has been noted only for the Caribbean ERS [12]. MAM SSTAs in the Tropical North Atlantic affect the Caribbean ERS [12], while MAM SSTAs in the TNA and Equatorial Atlantic have a dipolar effect on the ERS of Trinidad. Of note for the Caribbean LRS is the significant correlations with JJA SSTAs in the Tropical Pacific, TNA, and Equatorial Atlantic [12]. The Caribbean Sea's SSTAs also affect the LRS of the Caribbean [16]. Of these four regions, the JJA SSTAs of the Tropical Pacific and the Caribbean Sea significantly affect the LRS of Trinidad in conjunction with the South and North Pacific, and to a lesser extent, the North and South Atlantic Oceans. From the seasonal analyses, we find that the ERS rainfall anomalies of the island state are weakly influenced by concurrent SSTAs in the tropical Atlantic, the Pacific, and the South Atlantic (Figure 6c). In addition, the LRS rainfall anomalies are primarily influenced by concurrent SSTs in the Tropical Pacific, although weakly (Figure 7d). These results contradict the current understanding of how these oceans affect Caribbean rainfall. Instead of the two oceans affecting the ERS, interannual variability in the Caribbean's ERS rainfall is primarily related to the Tropical North Atlantic's SSTAs [12]. While the Pacific affects the LRS of Trinidad, both the Pacific and the Atlantic (equatorial region) affect the interannual variation in the Caribbean's LRS rainfall [12,14–17].

3.1.9. The Gulf of Mexico, A New Region of Interest as A Possible Rainfall Predictor

One region that is noticeable on the correlation maps is the Gulf of Mexico. As it is small in size as compared with the Atlantic and lies adjacent to both the Caribbean Sea and the Atlantic, it is expected that the correlations between the PPTAs of Trinidad and the Gulf's SSTAs may have the same sign as the correlations with the SSTAs of the Caribbean Sea and the Atlantic. Instead, we note the Gulf of Mexico seems to have a more localized effect. DJF SSTs in the Gulf have a negative effect on the ERS of the southern islands, and at the same time, the Caribbean Sea and the Atlantic have a positive effect (Figure 6a). It is only in MAM that the negative effect of the Gulf of Mexico on the ERS is the same sign as the region of the Atlantic just east of the Gulf (Figure 6b), until the effect of the Gulf's SSTs disappears in the JJA. In a similar manner, DJF and MAM SSTs in the Gulf of Mexico have a positive effect on the LRS, while the Caribbean Sea and the Atlantic have a negative effect. The opposite effect on the Gulf of Mexico and the Caribbean Sea has been noted elsewhere. Wu and Kirtman [15] found that during MJJ, the pointwise concurrent rainfall–SST correlation over the Gulf of Mexico was negative and positive over most of the Caribbean Sea. They suggested that the rainfall response in the Gulf of Mexico was an atmospheric forcing of SST as the rainfall–SST and rainfall–SST tendency correlations were both negative. They also observed that the rainfall response over the Caribbean Sea is due to atmosphere–ocean interactions as the rainfall-SST correlations there were positive and rainfall–SST tendency correlations were negative.

3.1.10. The South Atlantic as A New Region of Interest as A Possible Rainfall Predictor

One feature of interest emerging from this study is the influence of the South Atlantic on monthly and seasonal precipitation anomalies of the southernmost islands of the Caribbean. In contrast, the Tropical South Atlantic does not influence regional Caribbean rainfall [9]. This study shows that the monthly SSTAs of the South Atlantic have weak negative correlations (−0.05 to −0.10) with Trinidad's monthly precipitation anomalies (Figure 4). However, stronger correlations were observed between seasonal SSTAs and seasonal precipitation anomalies. The ERS rainfall and South Atlantic SSTs between 30° S–50° S, 40° W–0° in DJF are negatively correlated with correlations between −0.3 and −0.4 (Figure 6). The negative influence decreases in magnitude as the season progresses into MAM and then JJA (which is concurrent with the ERS). Maximum correlations at concurrent time were −0.1. The subtropical region of the South Atlantic that influences the ERS also influences the LRS, but in a positive sense (maximum correlations of +0.3) and only in DJF and MAM (Figure 7). The Tropical Atlantic plays a greater role in the LRS than the Subtropical Atlantic. The Tropical South Atlantic, between 0°–30° S and the South American and African continents, has a negative influence on the LRS of Trinidad, with correlations of −0.4.

We note here that the areas of the South Atlantic that influence the ERS and LRS rainfall of the southernmost Caribbean island differ. The area of SSTA influence for the LRS (Figure 7) is to the north of the area of influence for the ERS at 30° S–0° and spans the region between northeast South America eastward to the African coastline. However, the correlation analyses in this work indicate that the ERS of the southernmost island of the Caribbean is affected by SSTAs at latitudes lower than 20° S and extending up to 50° S. As such, analyses for the Caribbean such as singular value decomposition (SVD) may need to investigate a larger domain than is typically considered.

3.1.11. SSTA Gradients

Another Atlantic feature of interest is the oppositely signed correlations in the North Atlantic as compared with the South Atlantic (Figure 7). This feature is more intense for the DJF and MAM correlations with the ERS than the LRS precipitation for Trinidad. The meridional gradient in SSTAs in the South Atlantic has been identified previously as a signature accompanying the Caribbean's late dry and ERS rainfall (defined as MJJ) [14]. This SST meridional signal is also present during the months of February–May, the rainy season of the northeast region of Brazil [47,48].

3.1.12. Weak Correlations between SSTAs and Island Precipitation Versus Moderate Correlations between SSTAs and Caribbean Precipitation

Of note in this study is that the magnitudes of the significant correlations (r) are small in comparison with those observed in previous studies for the Caribbean. For example, the correlation coefficients for the Caribbean's ERS, defined as MJJ in Ashby et al. [16], with SSTAs in the TNA, the Caribbean Sea, and Pacific Ocean have positive values between 0.30 and 0.64. However, Trinidad's ERS–DJF SSTA correlations for the TNA, the Caribbean Sea, and the Pacific were positive with lower magnitudes ranging between +0.1 and +0.3. In this study, we find that correlations between monthly SSTAs and monthly PPTAs range from −0.20 to +0.15, and correlations between seasonal SSTAs and seasonal PPTAs range from −0.4 to +0.5. Concurrent monthly SSTAs explain at most 4% (r^2) of the variability in monthly rainfall. In addition, concurrent seasonal SSTAs explain 25% of the variability in seasonal rainfall. Thus, concurrent Pacific and Atlantic SSTAs have a weak influence on Trinidad PPTAs, even though their influence is statistically significant.

3.2. Composites

3.2.1. ERS SSTA Composite Maps

During the DJF, two seasons prior to Trinidad's ERS, the SSTA composite displays a zonal warming for anomalously wet ERS conditions (Figure 8a). A positive SST anomaly is situated around the

Equator in the Tropical Pacific, the Caribbean Sea, and the Tropical Atlantic, extending to the coastline of Africa (Figure 8a). In contrast, during anomalously dry ERS years, the DJF SSTA composite maps (Figure 8d) show cool SSTs extending from the Pacific to the Caribbean Sea and the Atlantic Ocean, with SSTAs ranging from −0.1 to −0.4. The DJF Gulf of Mexico SSTAs are positive (+0.3 to +0.4) during dry ERS conditions (Figure 8d), while during wet ERS conditions, they are negative (−0.2). Thus, the Gulf of Mexico SSTAs display a change in size and magnitude between anomalously wet and dry ERS for Trinidad (Figure 8a,d). Furthermore, cool SSTAs are seen to the south along 30° S in the Pacific and the Atlantic. These areas also change sign from cool to warm SSTAs from anomalously wet to anomalously dry ERS in the DJF. This confirms that SSTAs in the Pacific and Atlantic are associated with both suppressing and enhancing rain in Trinidad.

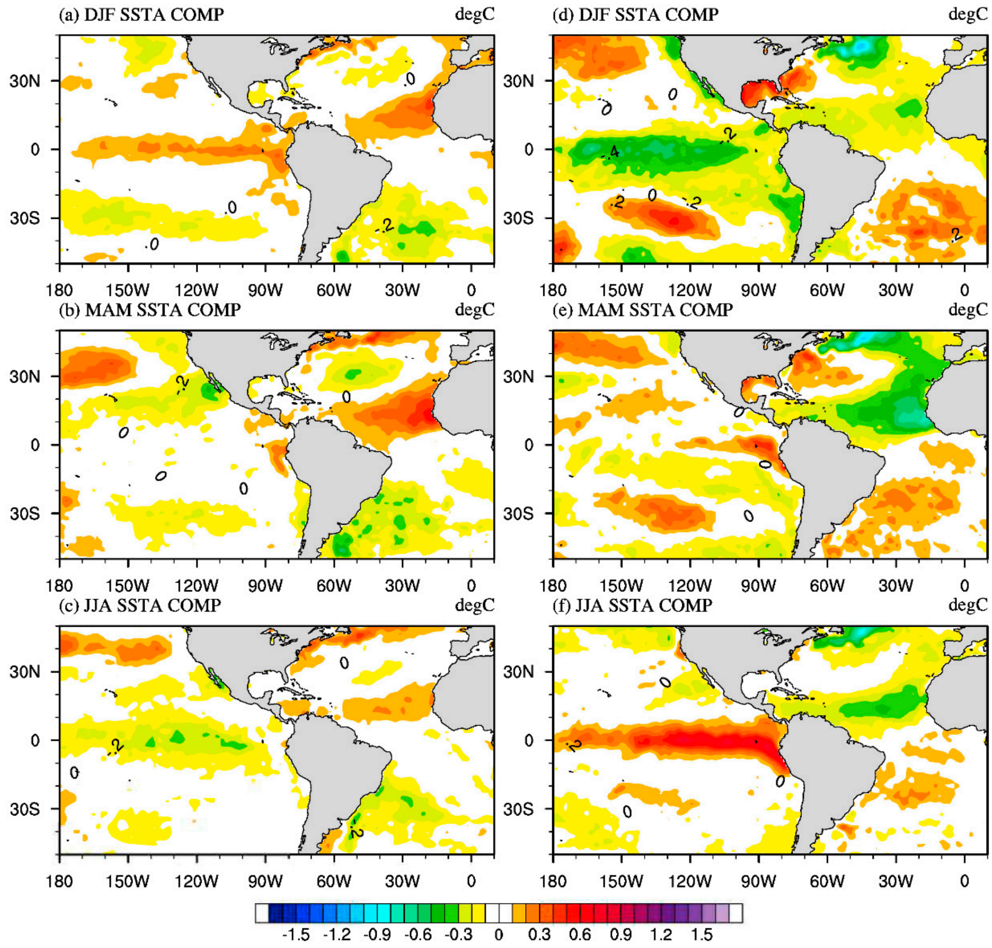


Figure 8. Anomalies are composited from 10 "dry" and 13 "wet" years in 1946–2006. Anomalously wet ERS SSTAs (**a**–**c**) and anomalously dry ERS SSTAs (**d**–**f**). Statistically significant anomalies are highlighted.

During MAM, one season prior to the wet ERS (Figure 8b), the zonal warming found along the Equator in the DJF has disappeared in the Pacific, whereas the Tropical Atlantic shows an increase in maximum warmth from +0.5 to +0.7 magnitudes. Prior to an anomalously dry ERS (Figure 8e), the TNA surface water cooling near the coast of Africa intensifies, with anomaly values ranging from −0.2 to −0.7. The Gulf of Mexico and the coasts of Central America, however, continue to experience warm waters.

Figure 8c shows very weak positive JJA SSTAs in the Atlantic Ocean that coincide with the wet ERS for Trinidad. A zonal cooling along the Equator in the Tropical Pacific (−0.5) emerges, illustrating the change from warm waters in DJF (Figure 8a) to cool waters in JJA. The warming of the Tropical

Atlantic water decreases in magnitude and size, with no significant cooling or warming in the Gulf of Mexico. In contrast, there is an intensified zonal equatorial band of warm waters (+0.4 to +1.6) in the Tropical Pacific during an anomalously dry ERS that extends along the coasts of South America (Figure 8f) to 20° S. In the Caribbean Sea, cool waters are present and extend into the Tropical Atlantic and the coasts of Africa.

In addition, warming in the Pacific gradually decreases from positive SSTAs in DJF to negative SSTAs observed in JJA (Figure 8a,c) leading up to an anomalously wet ERS in Trinidad. This observation is similar to the transition of a decaying weak El Niño signal (warm Pacific) into the onset of a weak La Niña signal (cool Pacific) in the following JJA [42]. The opposite evolution occurs for the dry ERS case (Figure 8d,f) for Trinidad; large cold SSTAs in DJF (Figure 8d) appear to decay in MAM and then develop into warm SSTAs in JJA, the beginning of the ERS in Trinidad. This decay of cold SSTAs is akin to La Niña conditions in DJF eventually developing into an El Niño signal in the following JJA. In this study, the seasonal composite maps leading up to an anomalously dry ERS in Trinidad show an anomalous warm Pacific event in JJA (Figure 8f). Our maps are in alignment with the results of Hastenrath [49,50], where higher than normal tropical Pacific SSTs coincided with dryer Caribbean conditions.

The Pacific and the Atlantic Oceans have oppositely signed SSTAs in the JJA SSTA maps for anomalously wet and dry ERS conditions (Figure 8c,f). This condition, where the tropical Atlantic is warm and the Pacific cool (Figure 8c), is generally associated with enhanced Caribbean precipitation [12,15] and was also observed by Enfield and Alfaro [18] when they considered the entire Caribbean rainfall season averaged over May to November [18]. Taylor et al. [12] found that the East-to-West SST anomaly gradients in the Tropical Pacific and Atlantic favor Caribbean rainfall in the late Caribbean rainy season. This scenario of the anomaly gradients was further confirmed by Spence et al. [14], who determined that there was a robust response in the Caribbean's LRS (August–September–October, ASO) and the Caribbean's early dry season (November–December–January, NDJ). Considering this analysis, further investigation into the SST anomaly gradient is needed to determine if this scenario only influences Trinidad's ERS.

Another feature observed on the composite maps was the transitions in the Atlantic warm pool. These influences shown here (Figure 8d–f) from the DJF to the JJA seasons are similar to those obtained by Taylor et al. [12], Wang et al. [46], and Gimeno et al. [51].

3.2.2. LRS SSTA Composite Maps

Three seasons prior to a wet LRS, the Tropical Pacific and part of the Tropical Atlantic are cool (Figure 9a), with the Tropical Atlantic SSTAs having smaller magnitudes. A weak SSTA dipole is also present in the Tropical Atlantic. However, the DJF SSTA pattern observed in the Pacific for a wet LRS is opposite to what is observed for the dry LRS (Figure 9e). A larger surface area of the Pacific Ocean has SSTAs reaching as high as +0.6, with the Tropical Atlantic and Caribbean Sea having positive SSTAs as well (Figure 9e).

The transition of DJF SSTAs (Figure 9a) into MAM SSTAs prior to a wet LRS (Figure 9b) is accompanied by a decrease in magnitude of the SSTA values in both the Pacific and Atlantic. This decrease in magnitude is replicated in the DJF-to-MAM SSTA map for below-normal rainfall conditions (Figure 9e,f). The TNA and the South Atlantic still have positive SSTA values in MAM, as the season prior. Furthermore, a warm South Atlantic is present leading up to a dry LRS (Figure 9e–h), unlike its very weak and decaying counterpart for the dry ERS.

The anomalously wet LRS SSTA maps (Figure 9a–d) show a change in sign in the Pacific Ocean from MAM to JJA. The originally cool waters in the Pacific (Figure 9a,b) become positive in JJA, with the Atlantic showing no significant SSTAs (Figure 9c). For the below-normal rainfall conditions for Trinidad, the summer SSTAs (Figure 9g) display a transition from positive SSTAs to negative SSTAs along the Equator in the Pacific. In the Atlantic, only the southern SSTAs show continuous warming from DJF (Figure 9e) to JJA (Figure 9g).

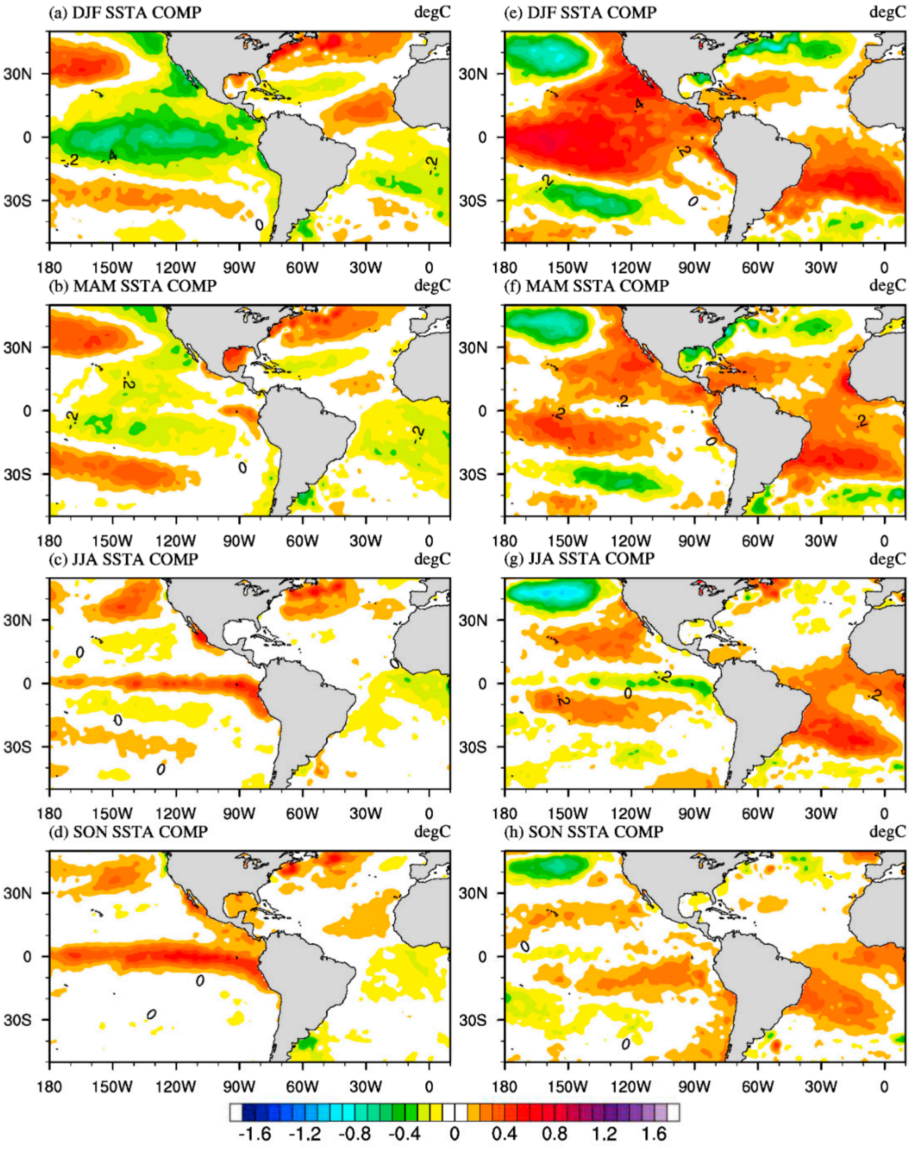


Figure 9. Anomalies are composited from 9 "dry" and 11 "wet" years in 1946–2006. Anomalously wet late rainy season (LRS) SSTAs (**a**–**d**) and anomalously dry LRS SSTAs (**e**–**h**). Statistically significant anomalies are highlighted.

The SON SSTAs (Figure 9d) show an intensified warming around the Equator in the Pacific from the season before. However, there is little influence from the Tropical Atlantic. The below-normal dry LRS SSTA map (Figure 9h) shows the disappearance of the cool SSTAs in the Pacific, with the warm South Atlantic presence remaining. In comparing the ERS and LRS conditions, it is possible that the warm SSTAs in the Pacific (Figure 9d) are responsible for the above-normal LRS rainfall conditions, while for the ERS, cool SSTAs modulate the rainfall (Figure 8c). This is opposite to what is seen for the below-normal rainy conditions. For the ERS, warm SSTAs in the Equatorial Pacific (Figure 8f) produce below-normal rainy conditions, but for the late season, their intensities are much reduced (Figure 9h). Stronger SSTAs were associated with a below-normal ERS rainfall, while for the LRS season, they are linked with above-normal rainfall.

While Trinidad's precipitation–SSTA composites are similar to those obtained previously for the Caribbean [12], it should be noted that the warm South Atlantic SSTAs seem to have some influence on Trinidad's LRS (refer to Figure 9e–h). Furthermore, there is also no presence of an SSTA gradient between the Tropical Pacific and Atlantic for either the above- or below-normal conditions for the LRS.

When comparing the LRS conditions for Trinidad with that produced for the Caribbean, there are notable differences. For a wet LRS Caribbean rainfall, the Pacific Ocean is dominated by a cool narrow band of SSTAs around the Equator. However, for a dry LRS, Caribbean rainfall is characterized by a band of positive or warm SSTAs around the Central and Equatorial Pacific [12]. Moreover, in the Tropical Atlantic, oppositely signed SSTAs are associated with both the wet and dry LRS [12]. For Trinidad's above-normal and below-normal LRS, the TNA SSTAs are only present in the DJF and MAM seasons (Figure 9) and are the same sign as the SSTAs in the Pacific Ocean. However, this study and that of Taylor et al. [12] are in agreement in that the TNA is more influential in the ERS as compared to the LRS.

The composite maps confirm the localized influence of the Gulf of Mexico (Section 3.1.1). In addition to the correlation analyses, the DJF and MAM seasonal composite maps for years of anomalously dry ERSs show a warming in the Gulf of Mexico and cooling in the Caribbean Sea (Figure 8d,e). Anomalously dry LRSs show a cooling in the Gulf of Mexico versus a warming in the Caribbean Sea (Figure 9e,f).

The composite maps for anomalously wet and dry ERS and LRS years also indicate the influence of the South Atlantic (Section 3.1.10). During anomalously wet ERS years, the subtropical Atlantic is cool in DJF, MAM, and JJA, and it is warm in DJF during anomalously dry ERS years (Figure 8). A much smaller region of the Subtropical South Atlantic is cool during DJF during years of anomalously dry LRSs (40° S–50° S, 30° W–0°). The composite maps confirm that the Tropical South Atlantic plays a greater role during the LRS than the Subtropical Atlantic as warm Tropical South Atlantic waters persist in all seasons, with the greatest warming occurring in DJF and MAM.

4. Conclusions

In this study, we investigated the influence of the Atlantic and Pacific Oceans on seasonal precipitation observed in the southernmost island of the Caribbean, Trinidad, and compared the results obtained for this single island with those of the entire Caribbean Basin. Several subregions of the Pacific and Atlantic have been identified here as potential influencers on the rainfall of the ERS and LRS of the southernmost island of the Caribbean since we considered a wider oceanic area, including the South Pacific and the South Atlantic, than that considered in previous studies. Our findings show the following:

- Different subregions of the Pacific tend to enhance and suppress ERS rainfall during DJF. Although this effect of the Pacific decays by MAM, its decay is accompanied by the appearance of a similar simultaneous effect in the Tropical Atlantic.
- Different subregions of the Pacific in DJF, MAM, and JJA are negatively correlated with LRS rainfall, while the Subtropical South Pacific is positively correlated in the same seasons. A similar effect on LRS rainfall is observed for different subregions of the Atlantic. By JJA, the NINO3 and NINO3.4 regions in the Pacific are the primary regions tending to influence LRS rainfall.
- While both the Pacific and Atlantic Oceans affect the ERS of Trinidad, it is primarily the Tropical North Atlantic that determines the ERS of the Caribbean. In addition, while the Pacific affects the LRS of Trinidad, both the Pacific and the Atlantic equatorial regions affect the Caribbean's LRS rainfall.
- An above-normal ERS is accompanied by warm SSTAs transitioning to cool SSTAs. In contrast, below-normal early seasonal rainfall is found in correspondence with transitions from cool DJF SSTAs to warm JJA SSTAs in the Tropical Pacific. In addition, SSTAs in the Pacific and Atlantic Oceans have opposite signs (warm Atlantic–cool Pacific).
- An above-normal LRS is accompanied by the transitions from a cool Pacific into a warm Pacific. However, for below-normal conditions, the composite maps illustrate the evolution of a warm DJF Pacific into a weak cooling signal, which then disappears by JJA, which is the start of Trinidad's LRS. This is in contrast to the ERS rainfall, where warm SSTAs in DJF transitions to cool SSTAs in

JJA for above-normal ERS rainfall while the cool Pacific waters transition into warm waters for below-normal conditions.

As such, the Pacific and Atlantic SSTAs two seasons prior to the ERS and the Atlantic SSTAs one season prior may be potential predictors for Trinidad PPTA. Although the correlations between SSTAs and PPTAs appear to be weak, they are significant. Statistical models may still retain as predictors the SSTAs of regions with weak correlations. Statistical models for the seasonal forecasting of rainfall at the island scale could be improved by using the SSTAs of the Pacific and Atlantic subregions identified in this study outside of the subregions known to be associated with Caribbean rainfall (Tropical Pacific, Tropical Atlantic, Tropical North Atlantic). These are the subtropical South Atlantic, the South Pacific, and the Gulf of Mexico. In addition, weak correlations also imply that the statistical seasonal forecasting models that we may consider should include factors other than SSTAs and historical rainfall such as atmospheric circulation parameters [35].

The myriad of seasonal SSTA and PPTA relationships with the Pacific and Atlantic suggest complex interactions that statistical models may not be able to sufficiently capture. For example, we noted the dual effect of different regions of the Pacific Ocean on the island's LRS rainfall and warm and cool regions of the South Pacific during anomalously dry ERS conditions. Studies using general circulation models (GCMs) will be better able to discern the processes leading to the dual effect of the oceans on precipitation. Linear correlation and linear regression are unable to fully explain these observations or the complex interactions that may lead to our observations. Nonlinear dynamical modelling such as GCM simulations will better clarify the SST interactions with the atmosphere that lead to anomalously wet and dry rainfall seasons for the southernmost Caribbean island. The results of this work can be extended to the larger context of forecasting seasonal rainfall for agriculture applications by assisting in selecting appropriate GCMs for seasonal forecasting, as suitable GCMs should be able to capture the main SST features in the Pacific and Atlantic that affect seasonal rainfall in the islands. The correlation features identified in this study can be used to determine which atmospheric–oceanic general circulation models (AOGCMs) could be used to provide uncertainty estimates of seasonal rainfall predictions. Appropriate selection of AOGCMs will then provide greater confidence in seasonal forecasting studies.

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